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Using video case studies to assess the impact of the use of GIS on secondary students' spatial thinking skills

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Abstract

We present the analysis of video case studies of students using geographic information systems (GIS) software to address sophisticated, locally-based problems in a secondary school course. Students show evidence of complex problem definition, hands on resolutions to conceptual and technological issues through the application of advanced geospatial processing, and choice of representations in their work, as well as the application of advanced geospatial processing. We are also conducting a quantitative study of the evolution of the students' use of spatial language and gesture through the course. Geospatial tools such as GIS demonstrate considerable promise in building students' ability to conceptualize and solve complicated problems with a spatial component, and the resulting spatial gains may benefit students in other scientific, technological, engineering and mathematical (STEM) domains.

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1. Introduction

Students' use of geospatial technologies, from geobrowsers like GoogleEarth to full-fledged geographic information systems (GIS) software like ESRI's ArcGIS, is increasing across a variety of grade levels in schools around the world. The use of these technologies helps students to develop both critical and spatial thinking skills as they learn to address questions where location, relative position, distance, direction, etc. matter and impact potential answers. The content ranges from earthquake risk and preparedness to global climate change to local environmental assessment to making business location decisions and much, much more. By giving students the tools and the skills to investigate topics that have importance and relevance to them, these technologies are both motivating and engaging.

The use of these technologies supports a focus on inquiry-based learning, a critical pedagogy in teaching science, technology, engineering, and mathematics. In fact, the National Science Standards in

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the United States [1] highlights inquiry-based learning as a key strategy for science pedagogy. There is also a desire to prepare students to address the problems of today and tomorrow. Geospatial technologies support and bolster 21st Century Thinking Skills [2] – these skills span content areas and focus on critical thinking and analysis, as well as communication.

We have developed an innovative curricular structure to both provide students with access to these tools as well as to carefully analyze the impact of them on students' spatial thinking skills. The Geospatial Semester is an ongoing project in which U.S secondary school students in their final year take a semester- or year-long class to learn about GIS and use it to explore locally-based projects. The class is taught by the local secondary school teacher, but university faculty regularly visit and are available for project and technical support. Students can also earn college credit for this class. More information is available at http://www.isat.jmu.edu/geospatialsemester.

Little research has been done to date on the affordances of geospatial technologies in supportingspatial cognition and reasoning. In this paper we will describe our affiliation with the Spatial Intelligence and Learning Center and how it led to our ongoing study, present the results from twodifferent case studies of student projects, and describe the initial results of an ongoing classroom video study on the impact of GIS software on secondary students' use of spatial language and gesture. We highlight how the students conceived of their problems, how they operationalized the requirements for solving them, and how they went about solving the problems. In doing so, we illustrate the use of GIS and related technologies to promote spatial approaches to problem solving.

2. Genesis of the project and collaboration with SILC

This project was funded by the National Science Foundation through a grant to the Spatial Intelligence Center, commonly referred to as SILC(See http://www.spatiallearning.org for more information). SILC is one of sixScience of Learning Centers, all of which were created to facilitate large-scale, interdisciplinary research on learning to address problems facing the United States. In SILC's case, this problem is STEM education; it is now well-known that the United States is not producing enough qualified STEM workers to fill the growing demand. SILC's contribution to addressing this problem is to understand and enhance the role of spatial thinking in STEM education. Substantial evidence now exists that spatial skills are a unique predictor of both achievement and attainment in STEM fields [3]. This holds true even after statistically controlling for the contributions. For example, in predicting who will become a (mechanical) engineer, measures of spatial skills turn out to be more predictive than either or mathematics or reading. SILC's position therefore is that understanding and enhancing spatial thinking can be a critical part of enhancing STEM education in the United States.

SILC's working model is to identify key areas in mathematics, science, and engineering education that could be improved through what we call *spatialization.* This process involves pointing out to teachers and students the role of spatial thinking in the topic that is being studied. A good example in early mathematics is measurement; measurement is an inherently spatial process, and students' progress in learning measurement is often inhibited through fundamental misconceptions regarding the nature of spatial extent and distance [4,5,6,7]. Making teachers aware of these limitations can substantially improve how teachers approach and teach the topic of measurement, and how children come to understand it and to use measurement tools such as rulers [8]. SILC uses this approach to identify and improve instruction in a variety of STEM disciplines, including mathematics, physics, geoscience, and engineering.

SILC funded the current project for two reasons. First, preliminary observations and discussions suggested that the Geospatial Semester was a highly successful model for promoting spatial thinking and problem solving in science education, and hence the SILC team wanted to study in detail how, what, and why students learned through participating in it. The Geospatial Semester is a strong example of the potential of spatialization as it encourages students to think about many science and engineering problems as inherently spatial in nature. Second, SILC believes that studying learning in the Geospatial Semester has the potential to shed light on how enrolment in a spatially-enriched course impacts student's methods for complex problem solving, and the benefits of approaching an issue within a spatial framework. Thus SILC views the relationship with James Madison University and the Geospatial Semester as reciprocal in nature—SILC helps to improve the Geospatial Semester, and at the same time gains critical information about how participating in spatially enriched programs facilitates the development of spatial thinking.

The collaboration with SILC brings to the project several important resources that would not be available otherwise. For example, one of SILC's methods for analyzing spatial reasoning involves detailed analysis of students' gestures, both while learning and while communicating what they have learned [9]. Likewise, SILC's expertise in the use of spatial analogies also brings to the forefront both research questions and analysis techniques that might not otherwise be available.

3. Methods

The work reported here was conducted in two high schools in Virginia. One is located in suburban Washington, DC, and the other is in a rural area in the Shenandoah Valley in western Virginia. The suburban school contributed one classroom of 28 children; the rural school contributed two sections of 12 each, taught by the same teacher. Following Institutional Review Board protocol, we obtained written informed consent from both students and their parents. Only those who provided consent were interviewed.

The data for this study came from interviews with the students throughout the academic year. The first came late in the first semester to capture a baseline comfort level with the technology and to begin discussing the upcoming personal projects. The second and third interviews were conducted about one third and two thirds of the way through the second semester, respectively. These interviews were meant to capture the learning process; the technological problem solving techniques along with how students dealt with the conceptual issues that arose throughout the maturation of the personal projects. The final interview was conducted after the completion of the final projects in which the students shared their conclusions along with their reflections on the process.

All of the interviews were conducted by a former middle school teacher who had experience with the geospatial technologies. Each interview was videotaped with a camera setup on a tripod to record the conversations. The interviews were done in the school at the computers the students were working on for their projects.

Our analysis in this paper is a qualitative, case-study of several examples of students' work. We highlight how the students conceived their problems, how they operationalized the requirements for solving them, and how they went about solving the problems. In doing so, we illustrate the use of GIS and related technologies to promote spatial approaches to problem solving. In a later section, we also describe ongoing analyses that focus on more quantitative outcomes.

4. Case analysis

In this section we present a qualitative analysis of the learning and thinking that goes into the completion of a semester-long project. We illustrate how participation in the Geospatial Semester facilitates inquiry-based problems solving, which includes the identification and solution of problems of personal and community relevance and interest, dealing with real world data and its limits and constraints, and the selection and creation of appropriate representations to solve the problem. In addition, these examples demonstrate the iterative nature of real-world scientific problems; the questions sometimes change as the student learns what data are and are not available.

4.1. Case 1: Locating wind farms near the East Coast of the United States.

The first project involves finding suitable locations for wind turbines off the east coast of the United States. There is considerable interest in using wind power to produce electricity, and many wind turbine "farms" have sprung up in rural areas in the United States. Driving from Chicago to Indianapolis, for example, one passes through several such farms, each with dozens of turbines. However, these land-based farms are often not near densely populated area and thus might not economically serve large cities.

An interesting alternative that does place wind farms near large cities is to locate them off shore. For example, wind farms are springing up off the east coast of the United States. Placing them within a few miles of shore allows for the relatively cheap transport of power back to large cities such as Boston. But doing so raises the serious challenge of where to locate the wind farms. There are many constraints; the farms need to be reasonably close to shore, but not so close they obstruct views from the shoreline or interfere with shipping. The wind speeds need to be great enough to generate sufficient power. The turbines can only be placed at particular depths, in relatively shallow waters, so this information also must be considered.

Two students went about finding possible solutions to these problems. As they had already been working with GIS for more than a semester, they are quite familiar with its affordances and constraints. They recognize the value of layering. For example, they began their explanation of their final project by saying that they are trying to "section off the areas where they overlap—where the wind speed datas [sic] and the depth data overlap…We're trying to create …basically another map of just the areas where they overlap…There's some areas where the winds are strong enough but the depths aren't right." They created a fly-through video of the east coast of the United States to show areas of overlap and eventually figured out how to use a raster calculator to create a file that showed only the areas that met both constraints.

At the end of the project they also considered how changing technologies might increase the number of possible sites. They represented possible sites with current technologies and then showed how these sites could be expanded if future technologies allowed for the building of turbines in water up to an additional 15 meters. This "think ahead" approach demonstrates the fruits of inquiry-based instruction, in that the students now "own" their problem and can reframe it based on possible changes. They are not limited to a narrow and concrete definition of the assignment but can think flexibly about alternatives and future developments.

These students have used GIS to solve a practical and important problem in an inquiry-based way. They have learned the importance of layering and overlap, and their implementation in GIS. They were able to propose possible solutions to an important, real-world problem and to anticipate how future technological developments could affect their findings. This level of inquiry and participation in decision making is precisely the kind of thinking we want to develop in our students.

4.2. Case 2: Understanding milk production and distribution routes.

In this case, we present a detailed analysis of the development over time of a solution. We interviewed the student four times across the school year. These in-depth, longitudinal analyses provide information not only about the final products but also about finding and specifying problems, tasks which are critical both to real science and engineering as well as to inquiry-based education.

This student is the daughter of dairy farmers in rural Virginia. Of special personal relevance to this student was the emerging interest in the "local foods" movement that encourages people to raise and consume agricultural products that do not require transportation across large distances. Americans choosing to eat bananas, for example, is often considered a violation of this goal because these fruits can only be raised in areas that are very far from the (continental) United States.

The student wondered whether the milk that her parents' farm produced was processed and consumed locally. She asked where does the milk that her parents' farm produces end up? Where is it processed, and where is it ultimately sold? This information is not necessarily easy to obtain. The farmers sell their milk as a cooperative and purchase the services of trucking companies to carry the milk to production plants, where it is pasteurized, bottled or cartoned, and packed for distribution to stores. From the perspective of a local dairy farmer, it is often not very clear where the milk ends up; a refrigerated truck comes periodically to pick up the milk, and a deposit is subsequently made in the farmer's account. There is often little connection between the farmer's production and the ultimate distribution of the milk. Thus asking, "Where does our milk end up?" is far from a trivial question, and finding an answer requires real-world spatial problem solving.

Step 1: Problem Finding. At first the student spent some time thinking about what kinds of problems she might solve for her final project. Her passion for dairy farming and food distribution focused her interest. When she was first asked (in December) whether she had begun to think about her research project, she noted, "My parents are dairy farmers" and that she was thinking about doing something "On milk production, with GIS, like mapping." The problem as this stage is loosely formed, but it is already clear that the students' personal interests in food production and what she is learning about GIS are coming together.

In the same interview, the student was asked about potential sources of data. Are the data that she would need available? Here again the student relies initially on her own experience, mentioning the name of the farming coop to which her parents and many other local dairy farmers belong. She stated that she "would have to go to them (the coop farmers) to get some data, based on maps of milk production." The student has begun to think about sources of data but does not yet know what is available and how it can be best obtained. As we will see, finding available and appropriate sources of data was a major challenge—one that reshaped to some extent the kind of question that she could ask and answer.

The interviewer and student discussed possible locations of dairy processing plants, naming several within an approximate 50-mile radius of the student's farm. At this point the student did not know where her parents' milk was processed and was going through several potential sites, choosing to focus at least initially on local or regional plants.

Step 2. Constraining the Problem. By the second interview (in February), the student had begun to realize how the availability of data would constrain her project. She noted that she "was not sure what she could really do" but that she "wanted to do a lot." She had some impetus to understand two important aspects of her project: The first was that her question was not only about her parents' farm but was about the general notion of the relation between the spatial distribution of milk production and milk processing. Thus she had begun to expand her inquiry from something specific to one based more on general questions that were relevant to other interested parties. Second, at the same time she realized that expanding the problem also made some constraints necessary. Therefore, she limited her analysis to dairies in two local counties and to those that produced only Grade A milk. She also realized the trade off between the quantity and quality of data, stating that, "Anytime you can narrow it down, you get more sufficient data". The student now grasps the kind of data she will need to answer her question and is thinking about where and how to obtain it.

What is obvious in the student's analysis is the iterative refining and focusing of her project. This is real scientific/engineering problem-solving in action. Although we may traditionally teach that science moves from theory to method and to results, we know in reality that these aspects of the scientific method are often intertwined and proceed in a reciprocal, iterative fashion. As the student thinks about what kinds and qualities of data can be had, her problem becomes more focused and more clearly defined.

In addition, the student also had begun to think about how to represent the data that she would obtain. She said, "I was thinking like maybe being able to symbolize from like, digitize…the dairy farm…and then maybe show the route the milk truck would take and symbolize it by a certain color." By the third visit (in April), the student had again both expanded and constrained her problem. She noted that, “Getting information for our project is really hard.” She had been able to obtain the most relevant data from one trucking company. This company informed the student regarding which dairies they served and where the milk was transported. The student simultaneously realized that relying on this trucking company’s data would make it impossible to study all the dairies in the two counties that she had earlier focused on, as the company did not serve all the dairies in the counties. Yet at the same time, establishing a working relationship with the trucking company also now gave her information about trucking routes. Once again we see the iterative relation between problem specification, data availability, and the search for additional data.

The student now began to understand that the distribution of milk to producers went well beyond the local area. She found out that the trucking company she was focusing on sends milk to at least two adjoining states, in some cases hundreds of miles from where it was farmed.

Now the student went about solving her problem. She had, from the trucking company, a list of pick up locations. The problem was to spatialize this information. She geocoded the addresses to create a map of the locations of each dairy.

Interestingly, at this point in the interview, the discussion then shifted much more to the students’ personal motivation and interests. She zoomed in on her family’s dairy and explained the production process, how many cows were milked (180, twice per day), where they ate and slept, how they were cleaned, and where they grazed. She even looked for cows on the aerial photograph she had acquired, but none were visible. This discussion and sharing of her personal connection to dairy farming may have been part of the motivation that led to the solution we describe next

Step 3: The solution. At the final interview, conducted in May, the student had nearly completed her project. She was asked to remind the interviewer of her hypotheses or questions, but in answering these questions, she also revealed that she now knew at least some of the answers as well. She noted, “We originally thought that, maybe not all, but most of the milk would stay in the [local] valley. But in fact, it can end up back in the valley, but it takes quite a course.” The student was surprised to learn that almost all of the locally-produced milk leaves the local area for production. Figure (1) is the students’ final map, showing where locally farmed milk is sent for production. Note that much of it leaves the state, with some going to eastern North Carolina and some going to Maryland.

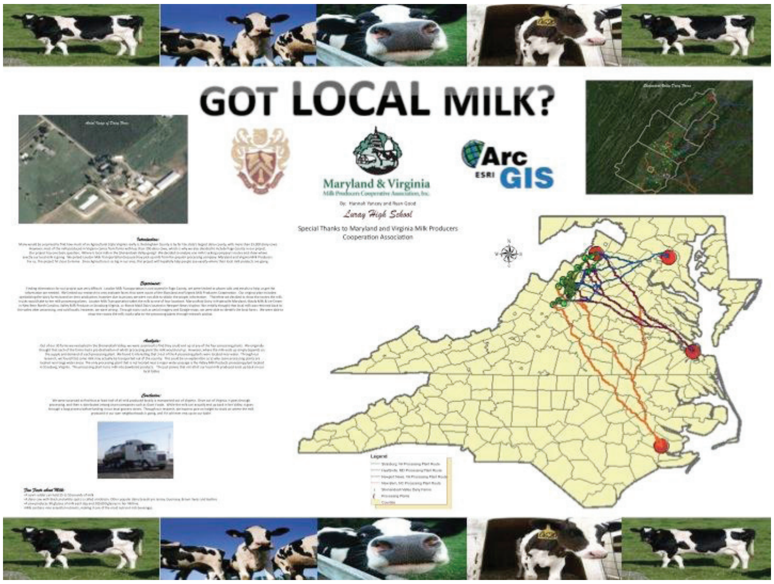

Fig. 1. Final presentation map for the Understanding Milk Production and Distribution Routes project

In solving the problem, the student again both expanded and contracted the range of her problem. She had expanded the counties included from two to four, but limited (because of data restrictions) the solution to (a) the particular trucking company mentioned above, and (b) a particular milk production company (that had production factories in the locations indicated on the map). In the end, the student was surprised to learn how far milk travelled for production. She also learned a great deal about the relation between a scientific question and the availability of data.

5. Ongoing analysis

Along with the qualitative analysis described above, we are pursuing a more quantitative analysis focused on the evolution of the use of spatial language and gesture by the students throughout the interview process. We are coding the video to examine whether the students show an increase in the use of both gestures and language as they advance through the class and build their spatial thinking and GIS software skills.

Through SILC, we will collaborate to investigate in detail whether, and to what extent, students' gestures reflect not only changes in the how much students know but also changes in how they think about the task. An increase in the number of gestures, and potentially the amount of spatial language used by the student, would imply a greater mental ownership of the relevant information regarding the student's project topic. Additionally, the students' gesture could illuminate underlying knowledge not spoken explicitly by the student; this type of gesture would imply a readiness to learn on the part of the student [10]. For example, we will code for the presence of relational gestures, which involve the use of two hands to show spatial relations among elements. For example, students who use GIS to plan the locations of wind farms might use one hand to represent a part of the coast and the other hand to represent the location of the turbines. In pilot work we have found that these relational gestures increase as students learn to approach a problem in a spatially-augmented way. Taken together, our quantitative measures will provide information regarding how and why participation in our programs promotes spatial reasoning [10].

6. Conclusion

We have presented the results of our research to date on the impact of geospatial technologies on students' spatial thinking skills. As described above, extended use of GIS does impact students' abilities to pose a spatial question, develop relevant data, analyze the question, and communicate potential answers. The students are clearly addressing sophisticated spatial concepts and they're demonstrating the ability to appropriately adjust their research question in response to the availability of data and their preliminary results.

The case studies also demonstrate the motivating power of spatial problems for these students. In the six years of the Geospatial Semester, this has been a constant theme in end of the year interviews. Many US students feel that much of their coursework has little or no relevance. Consequently, coursework with some relevance is highly engaging and motivating.

However, many questions remain to be answered. Many schools are not able to commit the resources for the extended exposure to GIS? What length and type of GIS instruction and use is required to produce these results? What spatial thinking skills gains are possible with shorter exposure? Does the increased use of spatial gesture and language continue to increase or does it plateau at some level of exposure? Does the improvement in spatial thinking skills translate to related areas?

Much work remains to be done in this area, but the initial results are promising. We look forward to continuing to expand upon this study to better understand the full potential of GIS for student learning.

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